Plastics Recycling and Waste Management in the U.S.

P. M. Subramanian, S.P.M.Technologies

ABSTRACT

The increasing awareness of the environment has contributed to concerns regarding our life styles and our indiscriminate disposal of wastes. During the last decade, we have been trying to address this complex problem, more aggressively. Discussed here briefly, are our efforts in the United States in addressing the issue of solid wastes and in particular, plastic wastes. These efforts have begun to show promising results. The municipal solid waste (MSW) produced annually has begun to decrease, e.g. from 211.5 million tons in 1995 to 209.7 million tons in 1996. Recycling rates and composting rates are increasing. Disposal in landfills is decreasing (from 60.9% to 55.5% in 1996). Waste disposal by combustion is also increasing. This is primarily due to the increased efficiencies of the new incinerators and their ability for the removal of particulates and harmful gases.

Plastics are a small but significant component of the waste stream. It is encouraging to note that the amount of plastics being recycled has grown significantly. In 1997, about 700 million pounds high density polyethylene (HDPE) bottles and 650 million pounds of polyethylene terephthalate (PET) bottles were recycled. Recycling of durable goods, such as automotive parts, carpets, electronic and appliance housings and parts are being explored.

Environmental compatibility and recyclability are being considered during the designing of new parts. Life cycle analyses and management are also being studied as tools for decision making.

Introduction

The pursuit of higher quality of life is a continuing goal for the people of this world. This has contributed to the increased consumption of goods and services. A consequence of such consumption is the production of increased pollution and large amounts of wastes. The goal of any sustainable growth should be that the efficiency of energy utilization in every step of the system, from the production of the goods to the disposal of the wastes, be maximized. The interdependence of each of these steps on the others in the total chain necessitates that we address the problems, in totality.This is an enormous and complex task. In this talk, we will focus only on the solid wastes produced and its management, and specially discuss plastics in the solid waste stream, in the United States. An integrated waste management approach will be considered involving efficient use of materials, recycling and disposal.

Municipal Solid Waste (MSW)

Most of the consumer generated solid wastes as well as a significant part of the industrially produced wastes in this country, are disposed of by landfilling. However, during the last decade, our environmental awareness has increased and as a consequence, questions are being asked regarding the viability of such indiscriminate disposal practices. As a result, substantial progress has been made in better management of the waste streams and more efficient utilization of land resources. The total MSW produced in the US has declined. Per capita generation of such wastes has also declined and recycling and composting activities have grown (Table1). The quantities of discarded packaging and durable goods have been reduced (Table 2) (Franklin 1998). Significant amounts of wastes are being recycled and / or composted (Table 3). Disposal of solid wastes by combustion has also increased. This is the result of the greater efficiencies of the newer waste-to-energy (WTE) plants which are engineered for complete combustion of the organic wastes and capture and removal of noxious gases and particles. The APC (1998), Dinger (1998), Greenberg (1998) and Porter (1998) have provided several overviews of the solid waste picture. The U. S. Environmental Protection Agency (EPA)'s most recent figures show that both the total and per capita waste generation rates have actually declined. US EPA is predicting a relatively stable per capita waste generation rate through the year 2000 as waste reduction efforts continue to have an effect (APC 1998).

Today, over 19,000 communities are involved in some form of recycling. 78% of the US population have access to recycling programs (Dinger 1998).

Table 1 Municipal Solid Waste in the U.S.

	1993	*1994*	*1995*	*1996*
Total MSW, Million tons	206	209	211.5	209.7
Per capita generation, lbs	4.4	4.4	4.4	4.3
Per capita discards, lbs	3.5	3.4	3.3	3.2
Recovery- recycling, composting, %	21	24	26	27

Contrary to popular belief, plastics are not the most prevalent material in landfills - paper and paper products account for the largest percentage of a landfill's contents (Rathje 1992, APC 1998). Food items and yard wastes are the next largest components. Among the other individual components plastics constitute the largest fraction (Table 2) (Franklin 1998).

Table 2 Composition of Materials in the MSW

Weight %,	*1995*	*1996*
Paper and Paper products	31.3	31.1
Glass	6.2	6.0
Metals		
Ferrous	4.7	4.8
Aluminum	1.2	1.3
Other non-ferrous	0.3	0.3
Total metals	6.3	6.4
Plastics	11.5	12.3
Rubber and leather	3.5	3.7
Textiles	4.2	4.4
Wood	6.4	6.8
Other	1.9	1.9
Food wastes	13.6	14.0
Yard trimmings	13.3	11.3
Misc. Inorganic wastes	2.0	2.1

The amounts of materials disposed in landfills, recycled or composted or disposed by combustion are given in Table 3.

Table 3 Management of MSW in the US

	1988	*1990*	*1994*	*1996*
Landfill, %			60.9	55.5
Recycling/ Composting, %	13	17	23.6	27.3
Combustion, %			15.5	17.2

Landfills

As shown in Table 3, most of the waste products are being disposed of by landfilling. During the 1980s, there was a perceived crisis over a lack of landfill space which led to fears that America would soon run out of room for its garbage. Images of garbage barges floating up and down our coasts were ingrained into our minds. While it is true that there were some localized landfill shortages in the 1980s, a shortage never occurred, nationwide. While the total number of landfills is decreasing, total landfill capacity is actually steadily increasing.

Between1990 and 1996, there has been a 17 percent decrease in waste being landfilled. National recovery levels reached 27 percent in 1996 and landfilled wastes declined from 83 percent of all MSW in 1986 to 55.4 percent in 1996. It has been calculated that at the current rate of waste generation, all of America's garbage for the next 1000 years will fit into a single landfill measuring 120 feet deep and 44 miles square (APC 1998).

Modern landfills are designed to safely entomb wastes so that their uncontrolled degradation does not endanger groundwater with pollutants. Such landfills could, in many cases, be used after they are capped, to construct parks, golf courses and even airports.

Plastics and Plastic Wastes

Plastics have become an integral part of our lives. The amounts of plastics consumed annually have been growing, steadily (Table 4). Its low density, strength, user-friendly design and fabrication capabilities and low cost, are the drivers to such growth. Besides its wide use in packaging, automotive and industrial applications, they are extensively used in medical delivery systems, artificial implants and other healthcare applications, water desalination and removal of bacteria etc. Usage of plastics, in preservation and distribution of food, housing and appliances are too many to mention here. Specially designed plastics, have been an integral part of the communication and electronics industry - be it in the manufacturing of chips or printed circuit boards, or housings for computers. They are also integral components in the preparation and delivery of alternative energy systems such as fuel cells, batteries and even solar power.

Given such pervasiveness, it is little wonder that plastics contribute to an increasing volume in the solid waste stream. In the MSW, in 1996, plastics amounted to about 12%, by weight (Franklin 1998). Table 5 describes the amounts of plastics (thousand tons) in the solid waste.

The waste plastics collected from the solid wastes stream is a contaminated, assorted mixture of a variety of plastics. This makes their identification, separation and purification, very challenging.

Table 4 Growth of Plastics in MSW

Year	*% Plastics in MSW*
1960	0.5
1970	2.6
1980	5.0
1990	9.8
1992	10.6
1994	11.2
1995	11.5
1996	12.3

Table 5 Plastics in Municipal Solid Waste (1996), (1000 tons)

Durable goods	6260
Nondurable goods	5350
Bags, sacks and wraps	3220
Soft drinks, milk etc containers.	1350
Other containers	1280

In the plastics waste stream, polyethylene forms the largest fraction, which is followed by PET. Lesser amounts of a variety of other plastics can also be found in the plastics waste stream (Table 6).

Table 6 Types and Quantities (Thousands of Tons) of Plastics in MSW

Polyethyleneterephthalate (PET)	1700
High density polyethylene (HDPE)	4120
Low density polyethylene LDPE/HDPE	5010
Polypropylene (PP)	2580
Polystyrene (PS)	1990
Other	3130

Integrated Plastics Waste Management

Any attempt to manage such large quantities of a diverse, contaminated mixture of plastics in an energy efficient and environmentally benign manner needs to be considered using an integrated approach. This would require that we examine critically the various steps in the life of the plastics such as the raw materials for their manufacture, the manufacturing processes, design and fabrication of the finished products, possible reuse of those items, and the proper disposal of the wastes etc., in totality.

Such an integrated waste management concept comprises of

* Source reduction,
* Reuse
* Recycling
* Landfill
* Waste-to-energy conversion

Source Reduction-Conserving Energy

It has been reported that only about 4 percent of the United States' energy consumption are used in the production of all plastics (APC 1998). Franklin Associates, Ltd., a leading practitioner in life cycle studies, has conducted research to compare the life cycle energy impact of plastics and alternative materials. One study compared the energy required to manufacture, use and dispose of common packaging items with the most likely non-plastic alternatives. Franklin found that by using plastic packaging, product manufacturers save enough energy each year to power a city of 1 million homes for roughly three-and-a-half years (APC 1998). Rathje (1999) has analyzed 'carrying capacity ratio's of different packaging materials. Glass has a value of 1.9 indicating that to carry 1.9 ounce of juice, one needs 1 ounce of glass. 'Plastics' has a value of 34 meaning that 34 ounces of juice could be carried in 1 ounce of plastic. Paper has a value of 6.9 and Aluminum 21.8.

Source Reduction-Efficient Use

An important aspect of the integrated waste management approach is to minimize the amount of plastics used. By employing improved manufacturing technologies, wastes produced during manufacturing processes have been reduced significantly, by the resin manufacturers and converters. Parts are being designed to have adequate strength, with less weight. Efforts are made to reduce the number of different types of plastics in any given assembly. Recycled plastics are often considered as raw materials for manufacture of a variety of parts, particularly in the automotive and industrial areas.

Since 1977, the weight of the 2-liter plastic soft drink bottle has been reduced from 68 grams to 51 grams, a 25 percent reduction. That eliminates the need for more than 206 million pounds of PET each year. The 1-gallon plastic milk jug has undergone an even greater reduction, weighing 30 percent less than it did 20 years ago. For several applications, milk and several juices are being packaged in recyclable pouches, which weigh substantially less than the rigid bottles. The lower weights, besides reducing the amounts of wastes produced, reduce the costs associated with freight and handling, as well.

The durability of plastics often contributes to their reuse in a variety of secondary applications. A large number of automotive parts are recovered from discarded vehicles or vehicles involved in an accident. These are dismantled, repaired and reused in many automotive repairs (Duranceau 1998). These recovered plastic parts contribute to a large reduction in the potential amounts of virgin plastic materials that would have been required otherwise.

Recycling of Plastics

Plastic recycling has grown appreciably during the last few years. Recycling of rigid plastic containers has grown to about 1.4 billion pounds- 704 million pounds of waste HDPE bottles and 649 million pounds of waste PET bottles, in 1997 (Table 7). At present, there are more than 1,700 businesses handling and reclaiming post-consumer plastics. A wide variety of new products, such as single-use cameras, park benches, sweaters, jeans, videocassettes, detergent bottles and toys are being made with or packaged in post-consumer recycled plastics. More than 1,500 commercially available products are listed in the Recycled Plastic Products Source Book published by the APC.

Table 7 Plastics Bottle Recycling Rates

Plastic Bottle, MM lbs	*1996*	*1997*	*Change,%*
PET Soft Drink	530	544	2.7
PET Custom	102	105	3
Total PET Bottles	632	649	2.8
HDPE Natural	403	414	2.7
HDPE Pigmented	253	290	14.9
Total HDPE Bottles	656	704	7.4
All Plastic Bottles	1308	1362	4.1

The production and consumption of virgin plastic resins have been increasing steadily. While the amount of plastics recycled also have increased simultaneously (e.g. by 4% in 1997), the recycling *rate* has declined (Toloken 1998). This is due to the weaker market demand for recycled resins in an economy where the virgin resins are priced very low- a situation compounded by the low energy costs and the poor global economy, currently.

Durable Plastics Recycling:

Durable plastics, as opposed to most packaging and 'convenience goods' which are discarded after a single use, tend to have a life of 3 or more years. Automobiles, computers, household appliances, carpets and fabrics fall into this category. The use of plastics in durable applications continues to grow as design engineers, manufacturers and consumers continue to rely on its performance, low cost and design benefits. The recovery of plastics from such 'durable goods' is complex. Often, they are integrated with several other plastic and non-plastic components. Their separation, recovery and purification require several steps and generally, the volumes of such materials available for recovery are limited. Nevertheless, several efforts are under way exploring the recycling of such products after their lifetime. Manufacturers of such products have committed to use of recycled materials, wherever possible, as a part of their total material needs. Business equipment and computer manufacturers, who are currently recovering precious metals from such products, are testing the recovery of plastic housings and other components from them. Automotive companies have major efforts in recycling of plastic components and try to use materials having recycled plastics content.

In the U.S., carpets consume over 2 billion pounds of polymers, mostly nylon 66, nylon 6 or polyesters. Carpet constructions consist of about 50% fibers or face yarn. The backing of the carpets is invariably polypropylene, attached to a layer of highly filled SBR latex. Recovery of the face fiber in a pure form, freed from the backing and the fillers etc is a complex process. Carpet manufacturers are introducing new technology to recover such carpet fibers and underlay, including preparation of pure monomers and intermediates.

Several studies and pilot programs in 'durables' recycling are under way. The objective of these projects is a comprehensive investigation of the technical, economic and ecological aspects of such recycling. Automotive shredder residue (ASR), a major, comingled mixture of waste products from end-of-life (EOL) automobiles is a subject of extensive investigation regarding its potential use for impact modification of concrete, pyrolysis, or as a fuel in energy plants. Economic modeling has complemented much of this experimental research. They include assessment of system economies for today's automobile recycling infrastructure and project the impact of different material and energy recovery options (APC).

Design for Recycling:

Until recently, very little attention had been paid to make components and systems that lend themselves to facile recycling at the end of their use. Combinations of plastic, paper, metal and natural products were used in combination without any consideration of the potential difficulties in recycling. For example, the soft drink PET bottle had a polyethylene bottom, polypropylene or aluminum cap and paper labels. Adhesives used in the assembly of the products often, prevent easy separation of attached plastic parts. With the increasing awareness for potential recyclability, designers are exploring new designs and material combinations. New simplified soft drink bottle constructions, automotive fascias, bumpers and instrumental panels are examples of such efforts.

Advanced Recycling Technologies

Another approach to the recycling of plastics wastes involves the generation of monomers and building blocks in high purity, from the plastic wastes, enabling the re-manufacture of the original or new plastics. Such novel recycling (e.g. glycolysis, ammonolysis, pyrolysis, etc.) represents a significant technological advancement that could supplement existing mechanical recycling techniques. These are often called "Advanced Recycling" or "feed-stock recycling" or "chemical recycling" (APC 1998). Commercial size plants to make the respective monomers from polyesters and nylon have been built or are under construction. While several technologies in these areas have been developed, large scale adoptions depend upon their economic viability.

Energy Recovery

Another important way to manage solid waste is to recover the energy value of products after their useful life. One such method involves combustion of municipal solid waste (MSW) or garbage in waste-to-energy (WTE) facilities. Modern energy recovery facilities burn solid wastes in special combustion chambers, and use the resulting heat energy to generate steam and electricity. This process can reduce the volume of MSW by as much as 90 percent. Today, there are 114 energy recovery plants, operating in 32 states throughout the United States, generating enough electricity to meet the power needs of 1.2 million homes and businesses.

Plastics are generally derived from petroleum or natural gas, giving them a stored energy value higher than any other material commonly found in the waste stream (Boettcher 1992). The energy values of several common materials are given in Table 8.

Table 8 Energy Values of Common Materials

Material	*BTU/ lb*
Plastics	
Polyethylene	19,900
Polypropylene	19,850
Polystyrene	17,800
Rubber	17,800
Newspaper	8,000
Leather	7,200
Wood	6,700
Average MSW	4,500
Yard Wastes	3,000
Food Wastes	2,600
Fuel Oil	20,900
Wyoming Coal	9,600

Polyolefins commonly used in packaging can generate twice as much energy as Wyoming coal and almost as much energy as fuel oil. When plastics are processed in modern WTE facilities, they can help other wastes combust more completely, leaving less ash for disposal. Several international and U.S. studies, including a 1995 report completed by the American Society of Mechanical Engineers (ASME) and a study sponsored by the U.S. Conference of Mayors in 1989, have found that there is no evidence to link the incineration of polyvinylchloride containing wastes with increased dioxin emissions. Such combustion processes could be a way of disposing the large volumes of contaminated automotive shredder residues, safely (APC 98).

In 1997, there were 112 energy recovery facilities operating in 31 states throughout the United States with a design capacity of nearly 101,500 tons per day (APC 1998)

Life Cycle Analysis and Management:

During the last 20 years, public opinion and environmental directives from governments have led to the evolution of methodologies to measure an industrial system's environmental impact. Today Life cycle analysis (LCA) has emerged as a tool in the development of public policy and in design decisions. It analyzes multiple attributes of a product or system from cradle to grave. It also has the unique ability to create a quantitative inventory listing of all process inputs and outputs (including environmental emissions and energy resources) from which tradeoff analyses can be made before making public policy decisions or large investments in products, or research (Lowman 1997).

In the United States, where landfill space is actually increasing, the EPA is in an information gathering stage, and is becoming more active in the area of Life Cycle Management (LCM).

Conclusion

The past decade has seen increased awareness of the environmental issues and general support for exploration and implementation of methods and practices to make our products and processes more environmentally benign. Consequentially, substantial progress has been made in the areas of environmental management. In the case of solid wastes including plastics, significant progress has been made in reducing waste and increasing the quantities being recycled. Chemical recycling to make monomers, in the case of nylon and polyesters, has been established and disposal of very complex and contaminated mixtures of plastics by incineration has been developed. While several new technologies have been developed, the amounts of materials being recycled appear to have reached a plateau. In the absence of additional legislative mandates, further progress in recycling of plastics might be slower, given the relatively high costs of recycling, the low cost of energy, and the low cost of landfilling. Yet, with a long-term perspective, greater dedication to higher environmental quality and life cycle analysis of products, growth of plastics and its recycling could become more important in the future.

Acknowledgement

Valuable discussions with Mr. John McAuley of Montell and Dr. Michael Fisher of the American Plastics Council are hereby acknowledged.

References

APC (American Plastics Council) 1998. *(http:// www. Plasticsresource.com/)*

Boettcher, F. Peter. 1992. "Environmental Compatibility of Polymers" *Emerging Technologies in Plastics Recycling,* P. M. Subramanian and G. D. Andrews, Ed.

Dinger, Peter W. 1998. "Recycling Perspective- As packaging recovery rates slow the new focus is durables recycling" *Modern Plastics Encyclopedia* A-34.

Duranceau, C & Lindell.T. 1998. "Automotive Recycling as Reuse: Investigation to establish the Contribution of reuse as recycling" *Society of Automotive Engineers* publication No.1430.

Franklin Associates Ltd, (1998) "Characterization of Municipal Solid Waste": 1997 Update (Prepared for the USEPA), Prairie Village, Kansas, May.

Greenberg, Eric G. 1998 "The solid waste: the once & future issue", *Packaging Digest,* November.

Lowman, Rodney W.1997 "Life Cycle Assessment and Public Policy Development for the Automotive Industry", Proceedings of the Total Life Cycle Conference and Exposition, Auburn Hill, MI, April 7-9. *(http:// www.Plasticsresource.com/topics/readingroom/speeches/ica_speech.html/*

Porter, William.1998. "Waste Prevention- is Recycling Enough?" *speech during American Plastics Council- Harper's magazine Forum (http:// www. Plasticsresource.com/topics/readingroom/speeches/transcript_harper.html)*

Rathje, William. 1992. "The Garbage Project", *University of Arizona*, 1992).

Rathje, William and Murphy, Cullen 1992. "Five Major Myths about Garbage and Why They are Wrong" Smithsonian, July. *(http://www.Plasticsresource.com/topics/disposal/articles/index.html)*

Rathje, William. 1999. "King of the landfill hill: Rathje talks trash" (reported by Roger Renstrom), *Plastics News*, March 8, p53.

Toloken, Steve.1998. " Plastic bottle recycling rate keeps sliding" *Plastics News* August 24, page 1.

(US. EPA Report 1998. "Characterization of Municipal Waste (MSW) in the United States",*http://www.Plasticsresource.com/topics/disposal/backgrounders/disposal _backgrounder.html*

List of Tables: